Surficial and Environmental Geology of the Western Cape Breton Highlands, Nova Scotia

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SURFICIAL AND ENVIRONMENTAL GEOLOGY OF THE WESTERN CAPE BRETON HIGHLANDS, NOVA SCOTIA

P. W. Finck

INTRODUCTION

Scope

The Nova Scotia Department of Mines and Energy (NSDME) began a study of surficial materials overlying the western Cape Breton Highlands during July 1990. Funding for the project was provided under the Canada - Nova Scotia Cooperation Agreement on Mineral Development. The study area is located north of Fielding Road and west of Highland Road between latitudes 46°20' N and 46°32' N and longitudes 60°45' W and 61°00' W (Fig. 1) on part of N.T.S. map sheets 11K/07 and 11K/10.

This report describes glacial and residual materials observed within the study area. In addition, glaciotectonic structures, hydrology, erosion, slope stability and acid precipitation buffering capacity of these materials are briefly examined within the constraints of the project. An interpretation of the regional glacial significance of the residual and glacial materials is included. The report is relevant to mineral exploration, geotechnical applications, environmental assessment and land-use planning. It is designed to accompany Map 1 (back pocket) and should be read with frequent reference to Plates 1 - 18 (back of text). This report is preliminary in nature and highlights many areas that warrant further detailed research. This is especially true for the environmental and geotechnical aspects of the report.

Methods

Initial assessment started with a synthesis of existing literature pertinent to the study area. Initial regional field investigations determined the accuracy of mapping by Grant (1988). Following verification of Grant's work, residual deposits were examined in more detail since exposures of these materials are some of the best in Nova Scotia.

Orthophotographs (1:10 000 scale) were used as base maps. Glacial and residual materials were examined in all road cuts. The presence and attitude of glacial tectonic features were noted. Till fabrics were measured in sections where transport characteristics of the till might add to the regional glacial history. The compositions of glacial and residual materials were compared to local bedrock geology in order to assist bedrock mapping, which was being conducted simultaneously by R. Horne. The presence of ablation lag and its provenance were noted. Map 1 (back pocket) was constructed using the 1:10 000 orthophotograph base maps and interpretation of 1:33 000 scale air photographs.

Previous Work

Glacial mapping at a scale of 1:50 000 was conducted in 1987 by INCO Limited and Sander Geophysics for SCOMINEX. These companies mapped an area from the Fielding and Kelly roads north to MacMillan Flowage, but did not note the occurrence of felsenmeer, saprolite and grus as units distinct from regolith. Surficial materials were mapped as regolith or till, with the till being subdivided on the basis of clast angularity.

The Geological Survey of Canada (G.S.C.) conducted regional mapping, compilation and air photograph interpretation of Cape Breton Island with the results being published in 1988 as two 1:125 000 scale colour maps (Grant, 1988) as well as several short papers in G.S.C. Current Research (Grant, 1971, 1974, 1975). Grant depicted the present study area as felsenmeer with lesser amounts of grus, rare small bodies of saprolite, glacial erratics and undifferentiated patches of till. From a

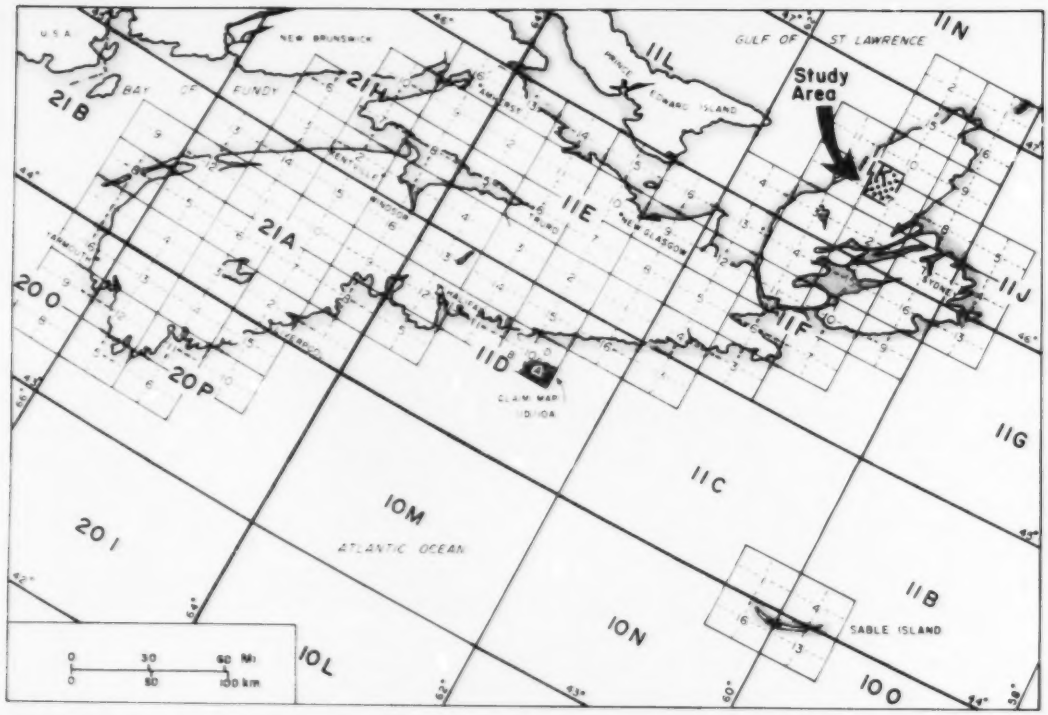

Figure 1. NTS and claim map divisions of Nova Scotia showing location of study area.

regional perspective his findings are similar to those of the present author.

Bedrock Geology And Physiography

The study area is located within the central portion of the Northern Tableland of Cape Breton Island. Bedrock is predominantly Silurian and older (ortho?)gneiss, minor schist and amphibolite, and Silurian to Devono-Carboniferous foliated and non-foliated granite. North to northeast structural trends in the bedrock are defined by foliation, brittle faults and ductile shears (Horne, 1991).

The Northern Tableland of Cape Breton Island is a planar surface with a gentle southward slope defined by the tops of the highlands (Plate 1), forming what is believed to be part of a regionally extensive erosional surface or peneplain. The age of this surface and its relationship to other concordant levels is speculative. Its age can be bracketed as pre-Quaternary and post-Carboniferous based on the lack of overlying Carboniferous strata and the occurrence of Quaternary glacial deposits. There are numerous other peneplains, paleoplains and unconformities with different suggested ages and elevations within the Atlantic Appalachian Region (see Grant, 1989). However, these regional correlations and ages are also poorly constrained and are speculative due to a lack of overlying datable material and control on post-erosional uplift or subsidence.

Goldthwait (1924) considered the Northern Tableland to be part of the Atlantic Upland, a peneplain rising from the south coast of Nova Scotia northwestward to the highlands of New Brunswick and northeastward to the tablelands of Newfoundland and Labrador. He suggested that planation occurred after deposition of the North Mountain Basalt of central and western Nova Scotia.

In the Nova Scotia offshore (Georges Bank Basin), Bell and Campbell (1990) recognized a regional unconformity marking the onset of seafloor spreading (the breakup unconformity). This surface truncates a series of horsts and grabens unconformably overlain by approximately 200 Ma volcanic rocks (uppermost Triassic to lowermost Jurassic). They also

recognized numerous other younger regional erosional surfaces (e.g. middle Cretaceous, upper Cretaceous, upper Eocene, etc). In the Scotian Basin the breakup unconformity is Late Jurassic - Early Cretaceous in age, correlating with breakup of the Iberian and North American plates (the Avalon disturbance). In addition, they recognized a minimum of seven unconformities, including three within the Cretaceous. The above is only a cursory examination of the offshore records but it serves to illustrate the point that any one or several of these cycles of erosion (and many others not mentioned) may be correlated with paleosurfaces recognized on land. However, until a method of dating the erosional surfaces on land is developed, any age assignment is speculative.

Previous Concepts of Glaciation

Ice flow history for Cape Breton Island was summarized by Grant (1971, 1976; Fig. 2). In northern Cape Breton Island, Grant mapped a Wisconsinan, southeast-trending regional ice flow, whereas in southwestern Cape Breton the flow was more easterly. Flow patterns reversed during late Wisconsinan phases, flowing toward the northwest, north and northeast from an ice centre located on the then-emergent continental shelf. Final ice flow was restricted to local ice caps. For example, Grant envisioned a small ice cap centered along the axis of the northern plateau with ice flow mainly toward the east, west and southwest (Fig. 2). Ice flow within the study area is generally considered to be non-erosive (i.e. cold based or representative of "warm based" stagnant ice; McKeague *et al.*, 1982).

SURFICIAL UNITS

Stratigraphy

Figure 3 is a schematic representation of the stratigraphic relationships between the major surficial units mapped.

Saprolite is considered to be the oldest surficial material in the study area. It is pre-Wisconsinan in age, based on the presence of overlying till at the Cape Clear Road type locality (TL3a). Dating the saprolite may yield the approximate age of planation of the highlands; however, a satisfactory method of accomplishing this has not been found. Along the Lee Spur Road, exposures of saprolite grade downward into a material similar to grus. Since both saprolite and grus are residual materials this relationship implies that grus is younger than the saprolite even though they are part of a weathering continuum. Pavich (1986) calculated a 1 cm per 3000 yr rate of saprolite formation from foliated granitic rock of the Virginia piedmont. Applying this rate of saprolite formation to the >2 m of saprolite at the Cape Clear Road type locality (TL3a), a minimum age of 60 000 yr is indicated. A >4 m section of grus on Coinneach Road suggests an age of 120 000 yr. Despite the great degree of uncertainty in these ages, the residual materials must be pre-Wisconsinan in age. Given the unknown true thickness of the residual sections on the Cape Breton Highlands these deposits could in fact be pre-Quaternary.

Grant (1988) suggests in his map legend that felsenmeer is a periglacial material of preglacial age. The author was unable to verify this relationship within the study area. At the Wildcat Brook Road type locality (TL2b), grus overlies jointed, weathered and rounded, competent bedrock. This suggests that felsenmeer is not part of a weathering continuum with saprolite and grus. Therefore, it is concluded that felsenmeer is younger than the saprolite or grus. If the felsenmeer is pre-Wisconsinan, and the saprolite and grus were regionally extensive (which is a reasonable conclusion), then presumably large areas of saprolite and grus were eroded prior to the last glaciation to expose barren bedrock. The barren bedrock would then have been shattered under periglacial conditions producing felsenmeer while preserving the remaining saprolite and grus. The author did not observe till overlying felsenmeer within the study area. The felsenmeer represents bedrock areas, unprotected by till cover, that were weathered by frost action following deglaciation. As a compromise point of view it is possible that the felsenmeer may be both preglacial and postglacial in age.

Colluvium is a product of mass wasting. Based on its genesis and position on valley sides it is inferred to be the youngest surficial material

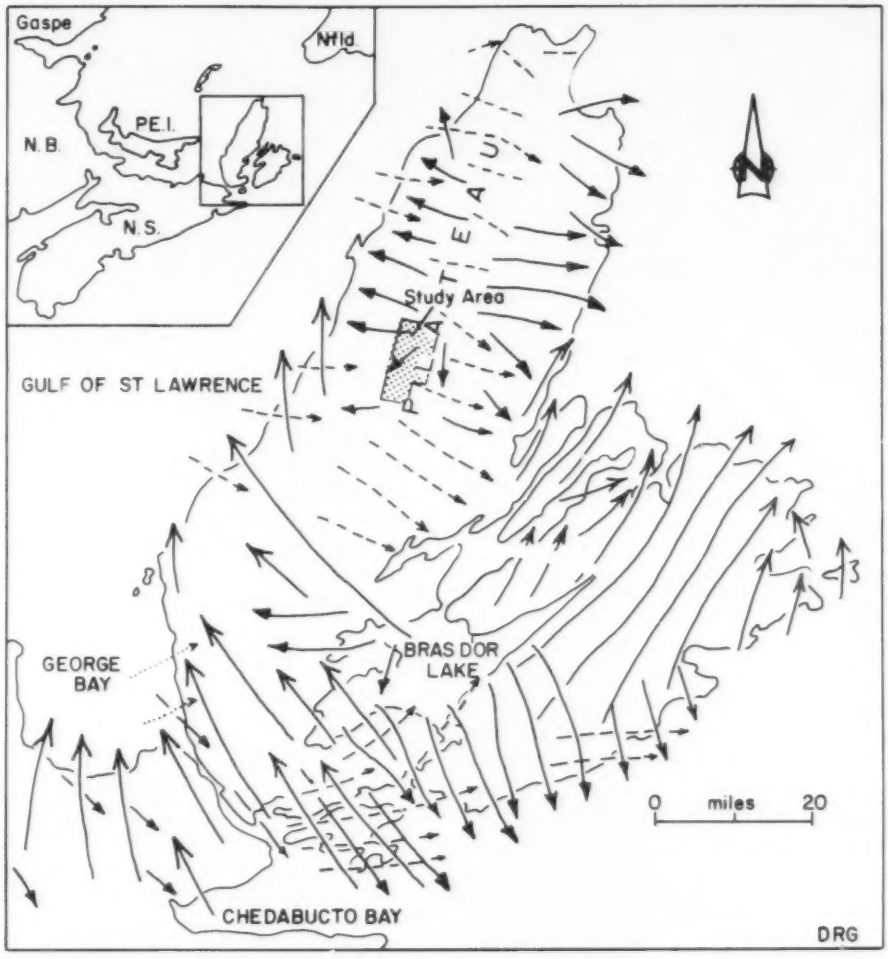

Figure 2. Generalized glacial movements in Cape Breton Island based on field observations and air photograph interpretation. Dashed arrows denote early flow from distant sources; solid arrows denote flow from several sources on or near the island active during maximum and late Wisconsinan phases; dotted arrows denote a late, local recession (after Grant, 1971).

mapped in the study area. Its age is variable and can be inferred to span the entire Holocene epoch. Preglacial colluvial material may be present in the valleys; however, it would be buried by younger glacial material or more recent colluviated material.

Saprolite

Saprolite is a soft, earthy, clay-rich residual material formed by isovolumetric weathering (at least on a large scale). Mineral forms present in the nonweathered parent bedrock are usually preserved in saprolite as pseudomorphs of the original minerals. Similarly, primary structural features are preserved.

Many exposures plotted on Map 1 are referred to simply as weathered bedrock because there appears to be a weathering continuum between grus and saprolite. Exposures of saprolite are local and do not have a distinct morphological expression. Therefore, air photographs are of limited use in extrapolating the distribution of saprolite in areas with no exposure. Since saprolite is transitional with grus, and is intermixed with areas of felsenmeer and deposits of till, its distribution is shown in one dimension as a pattern along access roads (Map 1).

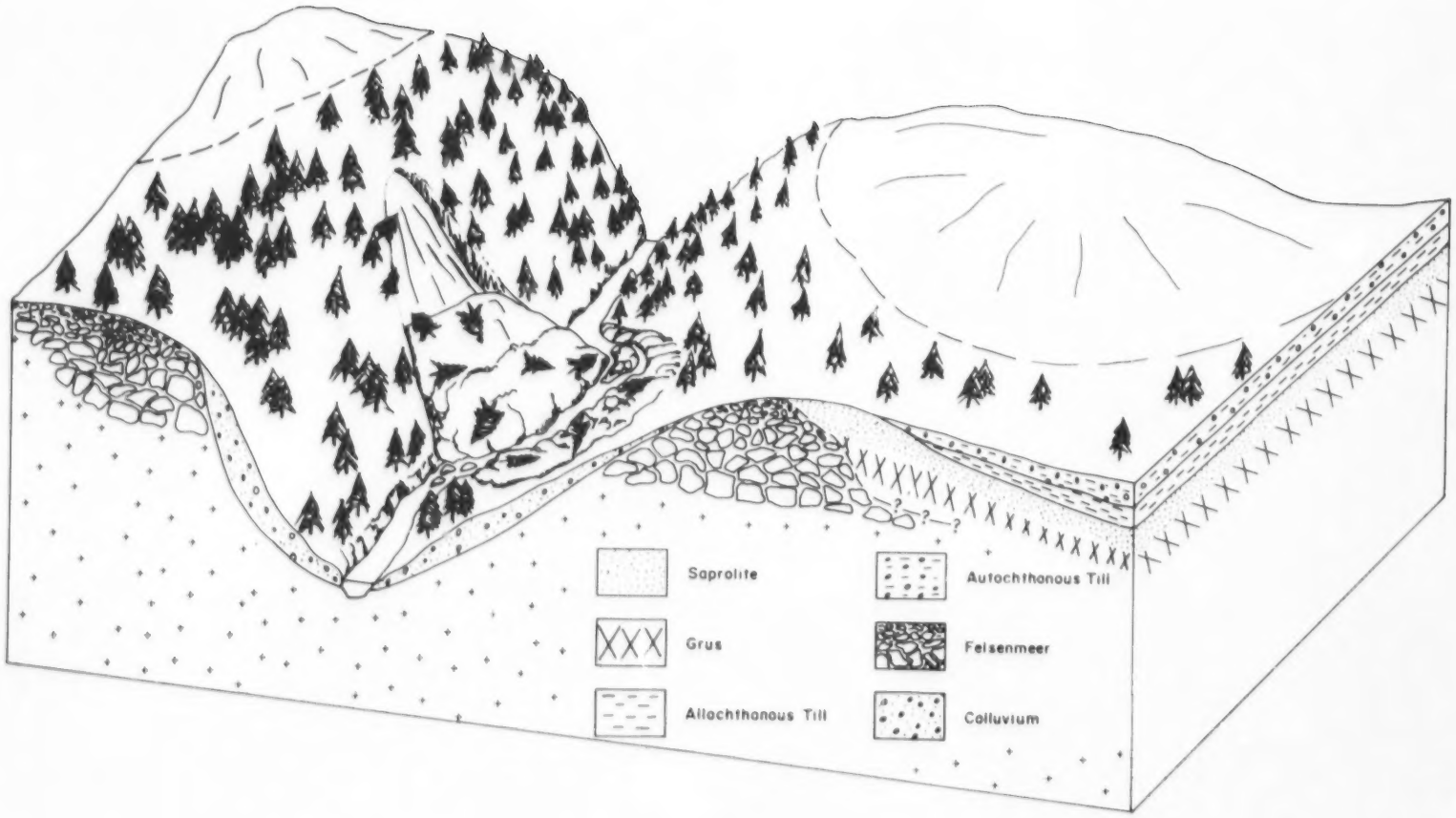

Figure 3. Schematic cross-section of stratigraphic relationships between surficial units mapped on the Cape Breton Highlands.

Two type localities for saprolite are (1) a gutter cut on the western branch of the Cape Clear Road leading to the lookoff (TL3a) and (2) a culvert washout 1.9 km from the eastern end of Center Road (TL3b).

CAPE CLEAR ROAD SECTION

The Cape Clear Road type locality was originally noted in 1974 by D. Grant of the Geological Survey of Canada (McKeague *et al.*, 1982). At this locality >2 m of pale yellowish-brown saprolite (its total thickness is unknown) can be exposed with a shovel over a horizontal distance exceeding 20 m (Plate 7). Here, and elsewhere within the study area, a vertical colour zonation exists from red and yellow at the top of the saprolite to grey, brown and green at the base. This is similar to 50 m thick sections of saprolite in the Northwest Territories where laterally continuous vertical colour zonation from red downward to green has been noted (Chiarenzelli, 1985). White bands of weathered bedrock are preserved within saprolite of the Cape Clear Road section (Plate 8). The banding reflects primary felsic layers within the parent Belle Cote Road Gneiss (Plate 9). In the saprolite, feldspar and biotite have weathered to poorly crystalline kaolinite, gibbsite and a minor component of iron oxide (McKeague *et al.*, 1982).

McKeague *et al.* (1982) observed a reddish-brown till containing clasts derived almost entirely from the surrounding granitic terrain overlying the saprolite at this location. The reddish-brown till graded upward into a nearly identical, but looser, diamicton. They felt that the looser diamicton was a derivative of the reddish-brown till produced by solifluction. The author observed that the saprolite is overlain by a clast poor, reddish-brown, silty, allochthonous till containing 8% - 13% highly rounded basalt and 16% rounded red-brown mudstone, siltstone and sandstone clasts. Source areas for these clasts are probably the Fisset Brook Formation and the Horton Group 15 km to the west-northwest (Fig. 4). The till also contains metasediments, vein quartz, quartz-feldspar porphyry, granite and locally derived angular Belle Cote Road Gneiss. The contact between the till and underlying saprolite is erosive and deformed where granitic cobbles (with or without associated till) are thrust downward into the saprolite (Plate 7). The long axis of the cobble in Plate 7 is oriented 85-265° with a 21° west imbrication in agreement with the bullet-nosed shape of the cobble. Where there are no cobbles near the interface between till and saprolite the contact is flat, sharp and erosive.

A greyish-brown, sandier till(?), up to 2 m thick, also occurs, overlying the silty reddish-brown till. In one area the contact was sharp whereas down-section along slope the reddish-brown and greyish-brown tills were observed to be interlayered. The greyish-brown till grades upward into a modern soil profile. This till contains only locally derived felsic granite and pegmatite (30%), Belle Cote Road Gneiss (66%) and felsic pink, fine grained quartz porphyry (4%). The interlayered nature of the contact between the two tills suggests that the upper till may indeed be partially a product of solifluction (in agreement with McKeague *et al.*, 1982). However, the distinct allochthonous vs. autochthonous nature of the clast geology of the two tills suggest that they are separate tills or different till facies.

Two till fabrics were measured in the reddish-brown till (Fig. 5). Both fabrics are similar with approximate east-west orientations and a large number of flat-lying clasts. A third fabric was measured in an area of interlayered greyish and reddish-brown till (Fig. 6). The fabric is multimodal with east-west, northwest-southeast and northeast-southwest modes. The fabric may be inherited from both tills and also may reflect a solifluction component. A fabric measurement was not attempted higher up in the section because of the possibility of creep, solifluction and/or dozer disturbance.

CENTER ROAD SECTION

The Center Road type locality is a >2 m thick section of saprolite exposed on the northwest side of a culvert washout. At the base of the section greyish to greenish-brown saprolite (Plate 10) is interlayered with a debris band of more competent bedrock material which is in turn overlain by saprolite. The debris band is composed mainly of weathered, tabular clasts of mafic gneiss (73%) with minor angular

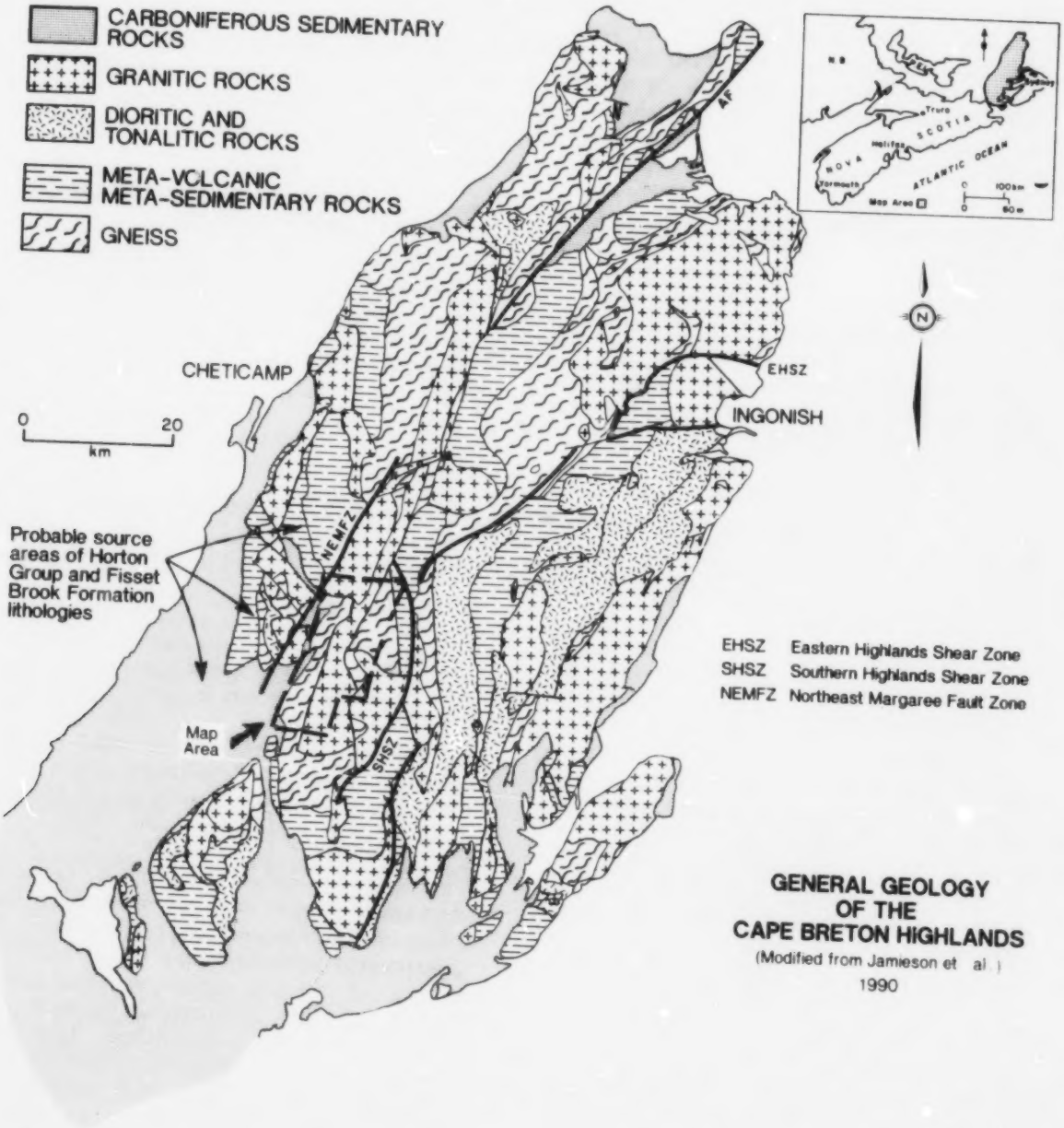

Figure 4. Regional geology map of northern Cape Breton Island.

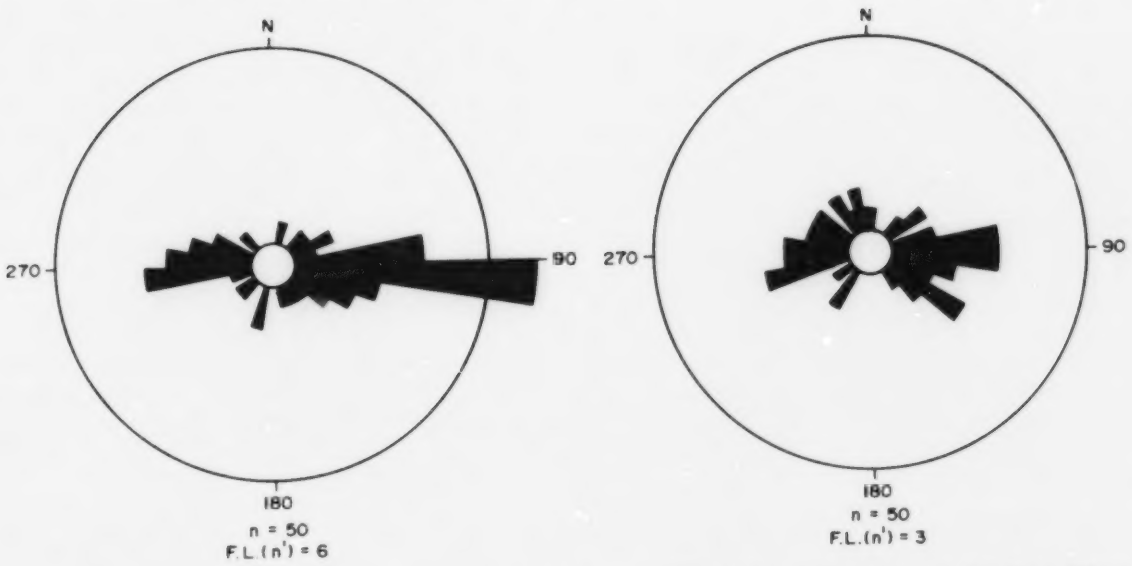

Figure 5. Till clast fabrics measured in reddish-brown till overlying saprolite at the Cape Clear Road type locality (TL3a). Clasts are plotted with respect to imbrication, i.e. east-dipping clasts are plotted on the east side of the rose diagram. Flat-lying clasts are plotted on both sides of the north-south axis.

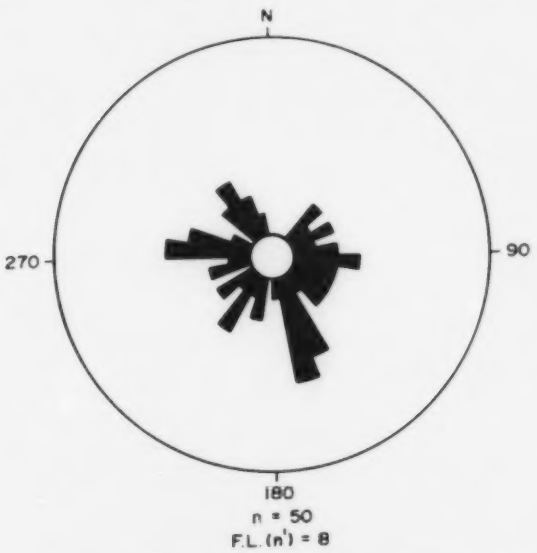

Figure 6. Till clast fabric measured in interlayered greyish and reddish-brown till at the Cape Clear Road saprolite type locality (TL3a). Clasts are plotted with respect to imbrication, i.e. east-dipping clasts are plotted on the east side of the rose diagram. Flat-lying clasts are plotted on both sides of the north-south axis.

megacrystic granite and/or pegmatite clasts (27%). Comparison of the saprolite with the weathering rinds on gneissic clasts leaves little doubt that the saprolite is derived from the weathered gneiss. The gneissic saprolite indicates the presence of an inlier or an extension of the Belle Cote Road Gneiss within the North River Monzogranite as mapped by Jamieson *et al.* (1987) and Horne (1991).

The saprolite is overlain by a variable thickness (<1 m) of compact, sandy till. The colour of the till is controlled by the amount of incorporated saprolite in the matrix and the amount of modern alteration from soil-forming processes. The contact between the saprolite and the till is gradational. The clast geology of the till is distinctly different from that of the saprolite debris band, containing 83% felsic, megacrystic monzogranite and/or pegmatite and 17% gneiss. The composition of the till is the same as that of an overlying one-boulder-thick ablation lag that contains 82% megacrystic monzogranite and/or pegmatite, 6% granodiorite and 12% gneiss.

Grus

Grus is the fragmental product of *in situ* granular disintegration (grain to grain

boundary fracture due to weathering) of granite and granitic rocks (Bates and Jackson, 1980). Hydrating grains of biotite fracture adjacent grains of quartz and feldspar (Crooke and Gillespie, 1986), resulting in disintegration of the rock. As such, coarse grained granitic rocks with greater than 10% biotite content are typically more susceptible to weathering than fine grained leucocratic granite (Crooke and Gillespie, 1986). This is consistent with observations by the author within the present study area and also on the South Mountain Batholith in southern mainland Nova Scotia. In both regions, coarse grained biotite monzogranite and granodiorite generally weather more than fine grained, less mafic leucomonzogranite.

Grus does not form a regionally mappable lithostratigraphic unit within the study area. Exposure of grus in road cuts is excellent; however, its distribution is local and it does not have a distinct morphological expression. It tends to be intermixed with saprolite, areas of felsenmeer and deposits of till. As such, extrapolation between exposures is not possible. On Map 1 the distribution of grus is shown in one dimension as a pattern along roads.

Two type localities for grus are (1) a gravel pit on the south side of Fielding Road east of Lee Spur Road (TL2a) and (2) a gutter exposure at the northern end of Wildcat Brook Road (TL2b).

FIELDING ROAD SECTION

At the Fielding Road type locality grus is derived from granodiorite of the North River Monzogranite (Jamieson *et al.*, 1987). The exposure is grey, massive and appears fresh, with the superficial appearance of the parent bedrock (Plate 4). Upon excavation the grus disintegrates into pebble to sand sized crystal fragments. Crystal fragments from the original granitic material (e.g. plagioclase) weather to gibbsite and kaolinite (Velbel, 1987). In this cut, the grus is *in situ* and reflects the underlying granodioritic bedrock. Approximately 100 m east of TL2a a 2.5 m deep washout exposes grus that grades upward into a more highly weathered and deformed material (Plate 5). The discoloured grus is glaciotectonically deformed with an apparent west to east plastic deformation. A debris band of diamicton containing clasts of pink, medium grained, non-deformed granite overlies the grus with a sharp contact. This debris band appears to be glacial in origin. The clasts are derived locally from dykes of more leucocratic material that commonly cut the North River Monzogranite, which is exposed in nearby road cuts (R. Horne, personal communication).

WILDCAT BROOK ROAD SECTION

The Wildcat Brook Road type locality reveals rounded and polished granitic bedrock at the base of a 3 m gutter cut (Plate 6). It is overlain by grus containing rounded boulders apparently derived from the underlying bedrock. In fact, the rounding and polishing of the outcrop is due to preferential weathering acting faster on the corners of the outcrop than on the flat sides. The rounding and polishing is not glacial in origin. The 'boulders' in the grus are core-stones: remnant, rounded fragments of the bedrock that remained *in situ* as weathering preferentially penetrated along joint systems in the parent bedrock. Core-stones may be mistakenly identified as ablation boulders, falsely suggesting a possible allochthonous source and a glacial transport history. This section illustrates the *in situ* relationship between core-stones and bedrock. It also illustrates the fact that exposures of grus can be used as outcrop for the purpose of bedrock mapping.

Till

Till is a diamicton deposited directly or indirectly by glacial ice. Deposits of till within the study area do not form mappable lithostratigraphic units. Exposures along roads are less than 3 m thick, though greater thicknesses are inferred in depressions and on valley sides. Till overlies and/or grades into weathered bedrock. Autochthonous till is laterally variable and is often indistinguishable from saprolite, grus and felsenmeer, making mapping difficult. Since the till cover is thin and does not have a distinct morphological expression, air photographs cannot be used to extrapolate between exposures. As such, the

distribution of till is shown in one dimension as a pattern along access roads (Map 1).

Three type localities for till are: (1) allochthonous and autochthonous till at the Cape Clear Road saprolite type locality (TL3a), (2) autochthonous till in gutter cuts on Second Forks Brook Road (North) (TL4a and TL4b) and (3) and till overlying saprolite/grus on John Peters Mountain (TL4c). Deposits of till at the Cape Clear Road type locality (TL3a) were described in detail in the section on saprolite.

SECOND FORKS BROOK ROAD (NORTH) SECTION

Material in gutter cuts on Second Forks Brook Road (North) has the appearance of grus. Clasts are weathered crystal fragments and highly angular rock debris in a dirty, brown, compact sandy matrix. However, close examination reveals that surface wash has removed fine matrix material, leaving a lag of weathered clasts, from what is in fact an extremely locally-derived till. The true genesis of the material is illustrated at location TL4a (Map 1) where a glacial erratic is incorporated in the till (Plate 11). At the western end of Second Forks Brook Road (North) large ablation boulders lie on the surface and are incorporated into surrounding sediment (TL4b; Plate 12). Although this material is extremely locally derived the presence of boulders in these positions (they are not core-stones) strongly suggests that this material is also till.

JOHN PETERS MOUNTAIN SECTION

Type locality 4c is a section of stony till overlying saprolite/grus at the western end of Center Road on John Peters Mountain (Map 1, Plate 13). The till overlies weathered bedrock with an erosive, sharp contact. A till wedge was observed but its sense of direction was not determined. Fabrics within the till show a strong 100-280° orientation with weaker northeast-southwest modes (Fig. 7). A large percentage of the clasts are flat-lying with the remainder having no preferred imbrication; therefore, it is not possible to determine the direction of ice flow.

GLACIAL EROSIONAL FEATURES

Glacial erosion on a large scale has not modified the well developed dendritic drainage pattern of streams within the study area. This is shown by the V-shaped stream valleys rather than the classic U-shaped glaciated valleys. The only piece of evidence for large scale glacial erosion are three small cirques located along the western margin of the study area. These cirques were mapped on the basis of morphology using air photographs (Map 1).

The lack of deep glacial erosion and the preponderance of weathered bedrock severely limit the formation and subsequent preservation of small-scale glacial erosional features. Within the study area striations are absent. However, southeast-trending striations were mapped by Grant (1988) east of the study area and by INCO (1986) northeast of the study area. The presence of these striations was verified in this study.

Scattered exposures of saprolite suggest that the entire area was at one point mantled by a deep cover of residual materials. However, it cannot be demonstrated that erosion of these materials was glacial in origin. Unless chemical weathering is proceeding at a rate equal to or greater than the rate of long-term denudation, saprolite, for example, will not be preserved. Therefore, a simple change in weathering rate could explain erosion of these residual materials prior to regional glaciation.

GLACIOTECTONIC FEATURES

Overriding ice will either erode from, deposit on, or freeze to and deform by internal plastic flow when passing over a solid bedrock substrate, depending on the subglacial conditions. In addition to the formation of till fabrics by preferentially orienting clasts within a till, structures such as folds, shear planes, till wedges and tension cracks may form as a result of deformation of a substrate by overriding ice.

Deformational features were observed in saprolite and till at the Cape Clear Road type locality (TL3a). The section reveals, from bottom to top, a sequence of brittle to ductile

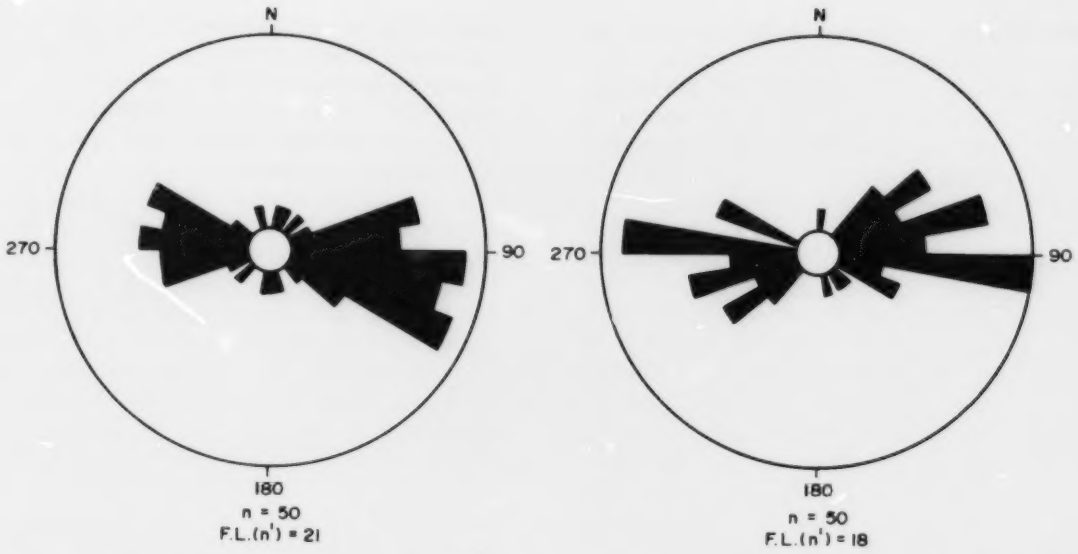

Figure 7. Till clast fabrics measured in a stony till overlying saprolite/grus on John Peters Mountain, type locality 4c. Clasts are plotted with respect to imbrication, i.e. clasts dipping east are plotted on the east side of the rose diagram. Flat-lying clasts are plotted on both sides of the north-south axis.

deformation. A primary subvertical felsic layer within more mafic Belle Cote Road Gneiss host rock was subjected to brittle deformation with an apparent right hand (east to west) offset (Plate 14). This displacement is accommodated along shallow, eastward-dipping (7° to 27°) shear planes that strike from 127° to 195°. Accompanying this displacement is deformation illustrated by rotation of mafic bands within the felsic layer (Plate 15). From the bottom to the top of the section the deformation becomes more ductile, as illustrated by the stretching, attenuation and horizontal rotation of numerous felsic layers that have been altered by weathering. In addition, displacement has resulted in the formation of drag folds within the weathered bands (Plate 14). At the saprolite - till contact a small till wedge intrudes from east to west into the underlying saprolite. A granitic, bullet-nosed boulder is wedged into the saprolite with accompanying infilling of till behind and under the boulder. Both the sense of injection and the morphology of the boulder indicate an east to west movement.

The saprolite type locality (TL3a) occurs on a 5° to 10°, southwest-facing slope (McKeague *et al.*, 1982). As such, it might be suggested that the above features are a result of solifluction or creep. Till overlying highly-deformed saprolite elsewhere within this section shows no evidence of solifluction or creep. The till - saprolite contact is sharp and erosive, except in the case of till wedges. Fabrics in the till are strong and unimodal. In addition, movement by creep is laminar. Soil creep does not shear across immobile rock or soil at depth (Bloom, 1978; p. 169). Deformation at the base of the saprolite is obviously brittle, unlike soil creep (Plate 14). The presence of till wedges and injected bullet-nosed boulders is diagnostic of glaciotectonic processes. Structures recognized within this section and elsewhere in the study area are similar to glaciotectonic features described by Hicock and Dreimanis (1984).

As described previously, at the Center Road type locality (TL3a) gneissic saprolite underlies and overlies a debris band of more competent gneissic clasts (Plates 10 and 16). The debris band strikes approximately northeast and dips toward the northwest. Individual tabular clasts within the debris band are also imbricated toward the northwest. The saprolite has an internal fabric, defined by fissility and compositional layering, that has an average consistent strike of 238° and dip of 013° to the northwest. The fissility and larger scale

compositional layering were formed by internal deformation of the saprolite. The superposition of stratigraphy resulted from glaciotectonic overthrusting at the base of a glacier carrying the debris band, and in turn the overlying saprolite, up and over the underlying saprolite along a shear plane.

Along the eastern end of Center Road glaciotectonic deformation of grus is well exposed in shallow gutter cuts (Plate 17). The unweathered, parent bedrock material is granodiorite of the West Branch North River Monzogranite (Jamieson *et al.*, 1987; Plate 4). An apparent foliation, which is not believed to be primary, is developed in the grus with variable strikes and dips ranging from 181°/005°W to 275°/022°N. The average strike and dip of five measurements is 237°/009° to the northwest, agreeing very closely with the strike and dip of the debris band at the Center Road saprolite type locality. However, the variability of the measurements suggests that the author may have measured strikes and dips on different limbs of folds. Coincidentally, folding was observed within granodioritic grus farther to the west on Center Road. At that locality it appears that fine grained rock debris formed along shear planes within the grus. The grus and shear planes (defined by the fine grained rock material) were subsequently folded and overturned.

On the south side of Fielding Road a culvert in a stream flowing into the West Branch North River has resulted in downcutting in the base of the stream at the culvert outlet and formation of a 4 m waterfall. At this site, 2 m of stony, moderately compact, reddish-brown till with a silty-sand matrix overlie 2 m of yellowish to strong brown weathered bedrock. The till has a strong fabric oriented 142° - 322° (dipping to the northwest) defined by clasts with length:width ratios of up to 6:1.

Felsenmeer

Felsenmeer (block field) is a thin accumulation of usually angular blocks, which may be allochthonous or autochthonous, with no fine sizes in the upper part, over solid or weathered bedrock (Bates and Jackson, 1980). Angular blocks or rock fragments form through the forces exerted by monomolecular films of unfrozen water that spread along and propagate pre-existing cracks in rocks (Bloom, 1978; p. 112). Freezing is thought to aid in the penetration of the thin films of unfrozen water into microscopic cracks.

Felsenmeer is the predominant residual material in the study area, covering most of the western half from Fielding Road north to the lookoff. It also covers the eastern portion from First Forks Brook Road (North) along the Highland Road to the northern margin of the map area (Map 1). Coniferous forest cover developed on thin soil over the felsenmeer is immature or nonexistent due to widespread clear-cutting. Logging operations have left green belts along brooks and small stands of noneconomic, mature, immature and dead trees (killed by spruce bud-worm attack).

Two type localities for felsenmeer are (1) well exposed gutter cuts and a borrow pit on the first left branch of Caribou Road (TL1a) and (2) a dozer scrape in the area mapped as felsenmeer on Wildcat Brook Road (TL1b).

CARIBOU ROAD SECTION

At the Caribou Road type locality the borrow pit reveals a 2 m section of angular *in situ* blocks of pink augen granite (Plate 2). Felsenmeer, here and elsewhere in the study area, is autochthonous and can be used to accurately map bedrock.

WILDCAT BROOK ROAD SECTION

A highly angular surface lag of felsenmeer is exposed at the Wildcat Brook Road type locality (Plate 3). Interstitial fines were washed out by rain and deposited in gutters and other depressions. Colour variations in the felsenmeer (Plate 3) reflect colour and lithological variations in the underlying parent bedrock. Quartz veins and leucocratic/mafic variations in gneissic bedrock are similarly expressed in the felsenmeer elsewhere within the study area.

Felsenmeer is usually found on the tops of smoothly rounded hills. Stratigraphic relationships between felsenmeer, other residual materials such as saprolite or grus, and

other glacial deposits were not observed. However, saprolite and grus were commonly found on valley sides overlain by till and partially protected from erosion. Felsenmeer was not observed overlain by till.

Colluvium

Colluvium is a loose, heterogeneous mass of soil and/or rock debris deposited by rainwash, sheetwash and/or creep. Creep is the gravitational product of slow downslope movement. Seepage pressure generated by groundwater flow and freeze-thaw cycles is an important mechanism aiding in downslope movement.

Colluvium occurs on the walls of stream valleys draining the interior of the Northern Tableland. It is mapped using air photographs and based on the relation of slope angle to mass wasting processes. Non-cohesive materials forming the debris on the valley walls have angles of repose between 25° and 40°. Within the study area gradients of the valley walls are very high and in many cases exceed the angle of repose of the overlying materials. The greater the gradient the more efficient creep is at transporting material from the top to the base of a slope.

Within the study area most valley walls are subject to rapid creep. Where till is present, downslope movement tends to produce a deeply weathered layer intermixed with organic materials. If more than one till is present a mixture or interlayering of the two deposits will occur. Effects of creep are difficult to recognize in material such as mainly weathered and frost-shattered rock. However, at the base of the Fielding Road a borrow pit exposes a section of colluvium that exhibits alternating layers of shattered rock, residual materials and diamicton.

Trees growing on colluviated slopes have curved trunks near the surface of the ground. This is due to a velocity gradient in the creeping surface layer; the tree trunk moves more rapidly down slope near the surface while the roots are anchored or are moving down slope at a much slower rate. The effect of this velocity gradient is that the base of the trunk is bent as the tree attempts to maintain an upright position.

GLACIAL EVENTS

Overview

During the Wisconsinan glaciation the Cape Breton Highlands were overridden by regional ice flows and, in addition, hosted one or more local ice caps. Sixteen per cent of the study area is mapped as colluvium. The occurrence of colluvium is related to slope stability rather than weathering or glacial processes. Forty-one per cent of the study area is mapped as felsenmeer, a product of mechanical and chemical weathering. The remaining 43% of the study area is composed of a combination of saprolite, grus and till. Examination of Map 1 indicates that till constitutes less than half of this area, approximately 20% of the map area. Therefore, weathering processes (both mechanical and chemical) have dominated over erosional and depositional processes associated with glaciation.

Regional Ice Flow

Early regional ice flow was toward the east-southeast in northern Cape Breton Island (Grant, 1971; Fig. 2) and formed the isolated deposits of reddish-brown, partially allochthonous till. At the Cape Clear Road type locality (TL3a) the flow direction is confirmed by the presence of allochthonous clasts derived from source areas to the northwest. Evidence of this early ice flow is also well preserved as northwest-dipping glaciotectonic debris bands at the Center Road type locality (TL3b; Plate 10). In addition, a strong till fabric measured in a section along the Fielding Road indicates that the material was deposited by a southeast ice flow. Striations mapped by INCO (1987; northeast of the study area) north of MacMillan Flowage record this flow event.

Local Ice Caps

On the western side of the Cape Breton Highlands, ice flow from Late Wisconsinan ice caps is believed to have been toward the west and southwest (Grant, 1971; Fig. 2). Direct evidence supporting this theory, such as clast

dispersal, was not observed within the study area. However, glaciotectonic deformation of residual material (e.g. orientation of shear planes, folds, and attenuated and sheared vein material in the saprolite: Plate 14) at the Cape Clear Road type locality (TL3a) suggests that ice flow was toward the west-southwest. This is consistent with the direction of till wedges and injected bullet-nosed boulders in the saprolite discussed in the previous section on glaciotectonic features. Clast fabrics in the overlying greyish and reddish-brown tills are believed to be composite fabrics reflecting both the early regional flow and the younger local ice movements. Similarly, clast fabrics in a reddish-brown till at John Peters Mountain (Fig. 7) are believed to be composite fabrics reflecting early east-southeast and later west-southwest ice flows.

Ice Dynamics

Surficial materials within the study area not only record directions of ice movement but also indicate subglacial conditions. The preservation of grus and saprolite and the lack of abraded bedrock suggest that glacial ice was non-erosive and was, therefore, generally frozen to its bed (cold-based ice) or stagnant. Movement, if present, would have been mainly through internal deformation. However, the presence of glaciotectonic features (Plates 5, 10, 14, 15, 16 and 17) indicates that glacial ice was at least locally warm-based and active.

ENVIRONMENTAL GEOLOGY

Acid Precipitation Susceptibility

BACKGROUND

The chemical composition of bedrock has a profound effect on the chemical composition of water draining a watershed. Bedrock terrains containing calcareous minerals, for example, will have a high buffering capacity when subjected to acid rain deposition (ability to absorb significant quantities of H^+ ions). Bedrock terrain underlain by unweathered granitic rocks has a low buffering capacity. However, the presence of glacial soils (till) overlying bedrock will also strongly affect the capacity of an area to buffer acid precipitation. The till may be mud rich (have an increased adsorptive capacity) and/or contain rock debris that will react with H^+ ions. A bedrock terrain overlain by thick till will have a higher buffering capacity than a similar area overlain by a thin covering of the same till. In addition to the above factors, the weathering state of the bedrock may affect the chemistry of water flowing through the material.

Shilts (1980) designates bedrock and derived soils within the study area as having a high to moderate sensitivity to acid precipitation. Similarly, the Lands And Integrated Programs Directorate mapped the area as having a high sensitivity to acid precipitation (Hirvonen, 1984). The area is described as having a low to uncertain buffering capacity, mainly by cation exchange with clay- to silt-sized material. Figure 8 is a contour map of lake water pH in Nova Scotia (from Stirling, 1987). Though there are only two sample sites in northern Cape Breton Island the map indicates that lake waters in the highland region are not greatly acidified, having pH values of 6.0 to 6.5 (this despite the low buffering capacity of bedrock and derived soils).

BEDROCK AND FELSENMEER

The dominant rock types within the study area are not reactive to H^+ ions on a time scale pertinent to a discussion of acid precipitation. This does not mean that the rocks are resistant to chemical weathering on a geological scale; note the presence of grus and saprolite. The area is underlain by igneous and metamorphic rocks commonly associated with areas of high to moderate sensitivity to acid precipitation (Shilts, 1980). Immediately east of the study area, occurrences of marble are mapped within the George River Group and other gneissic rock packages. However, a drainage divide occurs roughly along the Fielding Road with water flowing toward the west on the west side of the road and toward the southeast on the east side of the road. Therefore, these marble occurrences have no buffering effect on any acid input within the study area.

SAPROLITE AND GRUS

In areas where base flow to streams is through weathered bedrock, the chemistry of the

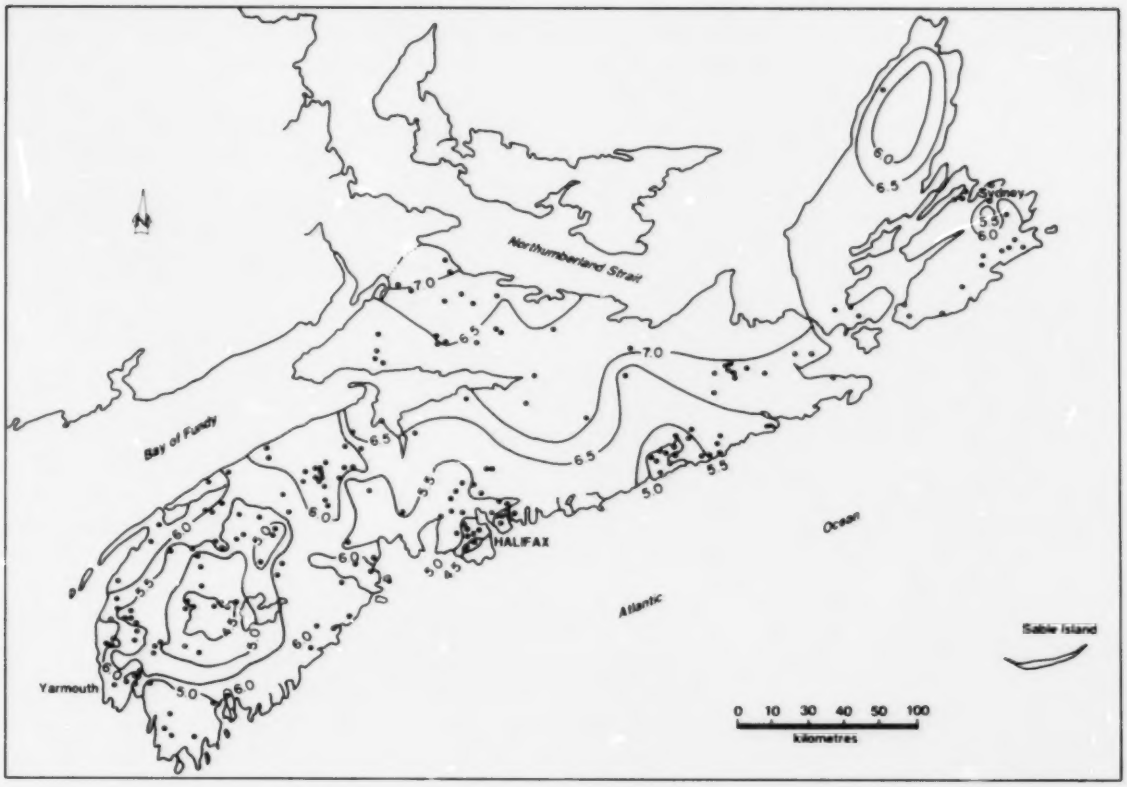

Figure 8. Contour plot of lake water pH in Nova Scotia (after Stirling, 1987).

streams may be controlled by the chemistry of the weathered bedrock. Given the significant areal extent and thickness of weathered bedrock in the southern portion of the study area (Map 1) it may influence the water chemistry of streams draining the area.

Modern soil-forming processes within the Maritimes region produce soils rich in minerals such as vermiculite, montmorillonite and chlorite (note the mineralogy of the modern soil overlying the saprolite of McKeague *et al.*, 1982; Table 4, p. 43). These phyllosilicates contain cations (e.g. Mg, Ca) that are easily replaced by H^+, thus providing some buffering capacity to the soil. However, within the deeply-weathered saprolite studied by McKeague *et al.* (1982), vermiculite and chlorite are absent or occur only in trace amounts (Table 4, p. 43) whereas kaolinite and gibbsite occur in concentrations up to 39%. Kaolinite and gibbsite are simple clays without primary, easily-displaced cations such as Ca and Mg. As such, their acid neutralizing capability is relatively low compared to the more complex phyllosilicates mentioned above.

In addition to the direct effect of acidification a primary concern regarding acid precipitation is its ability to mobilize aluminum. At a pH above or near 5, cations are released and aluminum is retained in the clay minerals. However, at a pH less than 5 aluminosilicates may react with H^+, releasing aluminum into solution. In addition, previously-formed clays, such as gibbsite, may dissolve, also releasing aluminum (National Rearch Council of Canada, 1981). Aluminum mobilized by acid is a concern because it occurs in a form (Al^{3+}) that is toxic to plants and fish.

TILL

As discussed previously, tills within the study

area occur as two types: (1) till derived from local bedrock and (2) till containing significant amounts of clasts and matrix material derived from external sources. The local tills are thin and have low buffering capacities similar to that of the local bedrock. The till containing material from allochthonous (far-travelled) sources has a higher buffering capacity. The matrix of the transported till is finer grained, based on visual estimates. More importantly, the source areas of 16% of the clasts in this till (the Horton Group to the west, Fig. 2) contain limestone. Though limestone was not identified in the clast fraction of the till, the matrix may be enriched in calcium. Unfortunately, the distribution of the far-travelled till is restricted within the study area and its effect on the overall chemistry of waters is limited.

STREAM pH

Figure 9 is a simplified contour plot of stream water pH measured by Mills (1989) for the central and eastern Cape Breton Highlands. Prior to contouring, the raw pH data were overlain on the regional bedrock geology at a scale of 1:50 000 and on the surficial geology for the area depicted on Map 1 (back pocket). No obvious relationships were observed between bedrock geology, surficial geology, catchment basins and pH. This is not surprising, given the relatively flat regional pH trend (Figure 8). It is reasonable to assume that the variable buffering capacities of bedrock or soil will have the greatest influence on regional pH levels in areas receiving high levels of acid deposition. The flat pH trend may simply be a reflection of the lack of acid loading of streams in the Highlands area. This is consistent with the observation that deposition of sulphate is more intense in southwestern Nova Scotia than in northeastern Nova Scotia (Stirling, 1987).

Erosion

NATURAL PROCESSES

A controlling factor in the evolution of the Cape Breton Highlands is the slow incision of streams into bedrock. Associated with this process is the removal of sediment transported by creep, solifluction and debris avalanche into the streams. In addition, material is removed as dissolved inorganic material in stream waters. Weathering of saprolite and grus is important due to the resulting release of both beneficial (e.g. K, Mg and Ca) and detrimental (e.g. Al) ions (Velbel, 1987). These reactions may control or strongly influence the chemistry of stream waters derived from areas containing significant thicknesses of residual materials. These are long-term, steady state processes.

Debris Avalanche

A debris avalanche (a form of landslide) involves the rapid movement of a mixture of weathered rock material, boulders and associated organic matter downslope. Failure is typically at the interface between the relatively unweathered bedrock and the overlying colluviated debris. Seven distinct debris avalanches within or near the study area were identified using 1:10 000 scale colour air photographs (flown in 1984) and 1:10 000 black and white orthophotographs (flown in June 1975; Table 1). These debris avalanches occurred on valley walls with slope angles of 17° to 59°, with an average angle of 34°. The avalanches have lengths varying from 60 m to 475 m and widths from 10 m to 30 m. Of the six avalanche sites in Table 1, one is a dual avalanche site with a younger (1975 to 1984) avalanche coalescing with pre-1966(67) avalanche channel (Nile Brook; Milligan, 1970). The remaining five avalanches occurred between June 1975 and 1984. The avalanches vary in shape from channels of constant width to cone and inverted cone shapes (Table 1).

Within the study area (indeed throughout the entire Cape Breton Highlands) avalanches into stream valleys draining the highland area are a significant geologic hazard. Of interest is the apparent increase in the frequency of these slides (one avalanche before 1966(67); one avalanche from 1966(67) to 1975 and five avalanches between 1975 and 1984). No data are currently available for the time period 1984 to present. The geological mechanisms controlling these slides are fairly well understood. However, there is usually a triggering mechanism that starts a slide, such as severe rain storms, lightening, earthquakes, blasting, or other man-made factors.

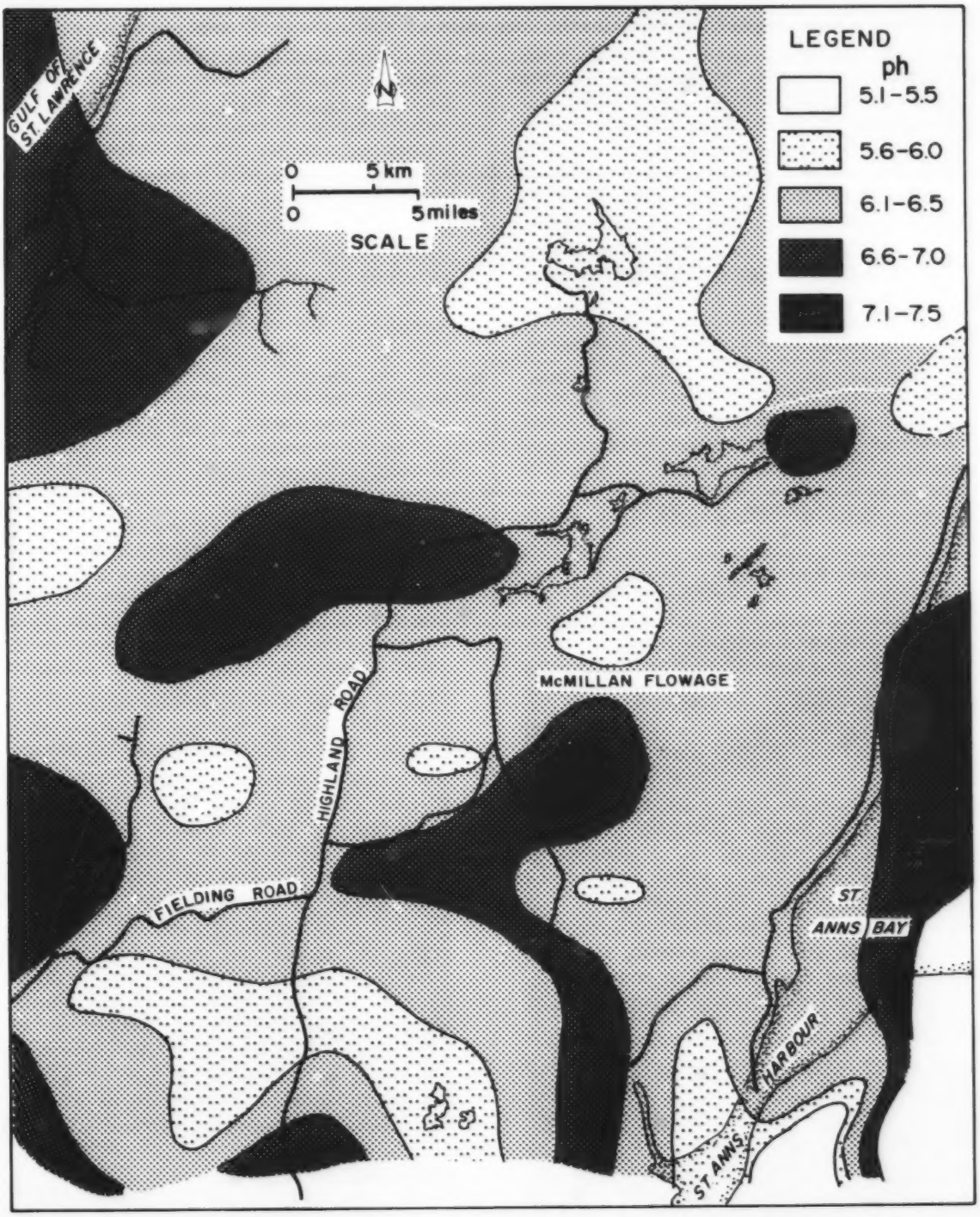

Figure 9. Contour plot of stream water pH in the northern Cape Breton Highlands (data from Mills, 1989).

Table 1. Description of debris avalanche sites observed within the study area.

Site #	Name	Max. Length	Max. Width	Max. Slope	Age	Description
1a	Nile Brook	475 m	30 m	34°	Pre-1966(67)	Widest in upper part of slide; narrows to a 10 m channel prior to entering Nile Brook; funnel shaped.
1b	Nile Brook	350 m	10 m	34°	Pre-1984 Post-June 1975	Widest in upper part of slide; narrows and coalesces with main debris slide (1a) prior to entry into Nile Brook; funnel shaped.
2	Marks Shanty Brook	225 m	10 m	27°	Pre-June 1975	Long, narrow (10 m) debris slide of general uniform width except at base where it pinches to form a narrow slide channel prior to entry into brook.
3	Peters Brook	150 m	25 m	Upper: 35° Lower: 22°	Pre-1984 Post-June 1975	Top of slide is 10 m wide, expanding to maximum width of 25 m at entry point into Peters Brook; cone shaped.
4	First Fork Brook	135 m	15 m	59°	Pre-1984 Post-June 1975	Channel shaped with a relatively constant width.
5	Second Fork Brook	200 m	30 m	46°	Pre-1984 Post-June 1975	Slide expands to maximum width of 30 m at entry point into small brook; cone shaped.
6	Rocky Brook	250 m	20 m	37°	Pre-1984 Post-June 1975	Maximum width of 20 m at top of slide, narrowing to small slide channel prior to entering brook.

Debris avalanches of the size observed in the study area are fairly innocuous when compared with debris flows in other parts of the world that travel for several kilometres in valleys, spreading out at the base of the mountain and burying entire towns. Certainly of greater concern is the potential for avalanches of moderate size blocking a valley and thereby damming the stream. The resulting build-up of water behind the obstruction, with potential for a sudden and violent release, is a real possibility and could endanger tourists (e.g. salmon anglers) and residents down stream of the natural dam.

Short-term, high-magnitude events such as landslides may represent a large proportion of the total eroded sediment in the highlands. Thus, any factor that increases the frequency of avalanches within the highlands will also increase sedimentation in the rivers and may have a detrimental effect on the lucrative sport fishery for salmon.

Solifluction

When the gradient of a valley wall exceeds the angle of repose of the overlying material (or a parameter such as the rate of water flow through the material changes, effectively decreasing the angle of repose) the valley walls become subject to landslide. Conversely, vegetation may anchor material to a rock face effectively increasing its angle of repose. Within the study area many valley walls have slope angles in excess of 40° (R. Horne, personal communication), which is above the angle of repose of most non-cohesive materials. Some colluviated surfaces on slopes have a wrinkled appearance (R. Horne, personal communication) indicative of solifluction. Solifluction is the downslope movement of debris at a rate of a few millimetres or centimetres per day or per year. It is intermediate between creep and landslide.

MAN-MADE EROISON

Two striking sites of erosion accelerated by human activity were noted within the study area. On John Peters Mountain (Center Road) a >146 m long, 1.2 m wide and 1.8 m deep gully (Plate 18) is cut through a combination of

till, saprolite and grus. The gully is cut on a 4° slope that shallows down hill. Within the study area, diversion drains constructed perpendicular to the main logging road and gutters are commonly used to carry excessive water away from the road and into the woods, thereby decreasing both the volume, velocity and erosion capacity of water draining down the gutters. Failure to construct this type of diversion drainage in the John Peters Mountain site probably contributed to the gullying. Original road design appears to channel water into rather than away from the road. It is uncertain to what degree this gullying may continue. However, the slope of the road decreases down hill so it is hoped that this gully will not grow significantly larger. Gullying can be a serious problem in weathered bedrock since there are no clasts to create a channel lag which would serve to armour the bottom of streams, thereby slowing the downward rate of erosion. In weathered bedrock, water rapidly cuts deep into the substrate and destabilizes the side walls. In Georgia, a gully 230 m long, 150 m wide and 20 m deep formed in weathered bedrock following deforestation (Ireland, 1939). Gullying can result in serious soil loss and may affect aquatic habitats by potentially increasing the sediment supply to streams.

A second example of man-made erosion occurs where the West Branch of the North River crosses Fielding Road. Erosion downstream of a culvert has formed a 4 m deep, 5 m wide and several tens of metres long gully cut through a surface layer of till into the underlying saprolite/grus. The culvert may have channelized or concentrated water flow into one small area increasing its erosive capacity and resulting in downcutting into the till and the underlying residual material. The eroded sediment was obviously discharged into the West Branch of the North River. It has not yet been determined if headward erosion is continuing.

Hydrogeology

RELIEF AND DRAINAGE

Relief along the western margin of the Northern Tableland is a combination of extremes. Flat-topped to gently rounded hills form a peneplain with precipitous breaks in slope where a well developed dendritic drainage system has deeply dissected the tableland. Upper parts of the stream valley walls are often near the maximum angle of repose of the overlying colluviated debris. The valley walls should be considered unstable, as shown by the nine debris avalanches observed within or near the study area. Lower walls of the stream valleys may be subvertical to overhanging (Horne, personal communication).

BEDROCK

Intergranular permeability within the granitic and metamorphic rocks is low to nonexistent. Permeability is anisotropic, being controlled primarily by the structural elements. Potential water yield depends on the size and number of structural elements within individual bedrock packages.

SAPROLITE - GRUS

An examination of Map 1 suggests that the occurrences of saprolite and grus (weathered bedrock) are regionally restricted and have a limited impact on the overall hydrogeology of the study area. However, weathered bedrock is commonly overlain by till (e.g. TL3a, TL3b, TL4c, Fielding Road washout, etc). In the highland area till tends to be found in depressions along the sides of valleys where there are generally few or no road cuts. As such the areal distribution of grus, saprolite and till is probably under-represented on Map 1.

Weathered bedrock is highly permeable. Within saprolite (and grus to a lesser degree) weathering reactions remove large quantities of oxides and in the process create void space. Isovolumetric weathering may result in saprolite with a porosity of up to 40% (Velbel, 1987). In addition, materials such as grus are extremely homogeneous when developed from compositionally and texturally uniform crystalline rocks; thus, there are few if any permeability boundaries within these weathered materials. The result is that rainfall quickly infiltrates deep into the substrate. This is illustrated by the total lack of surface water in borrow pits in the study area only

hours after a major rain storm. Indeed, a pit greater than 4 m in depth excavated in grus on Coinneach Road is totally dry. Only one borrow pit with standing water was observed within the entire study area, this occurred on a hillside and was probably spring-fed. This contrasts sharply with areas such as the South Mountain Batholith (SMB) where till overlies competent bedrock. On the SMB, borrow pits hold surface water for several days following heavy rains.

In areas of weathered bedrock the depth of the water table is probably controlled by the thickness of the weathered bedrock horizon. Based on the author's observations this horizon is significantly greater than 4 m thick. The bedrock/saprolite interface is a permeability boundary and as such the saprolite and grus may be a primary source of base flow

TILL

Deposits of till are thin (<3 m) in road cuts and usually overlie weathered bedrock. Visual examination of the till indicates that the proportion of clay, silt and sand as matrix material is highly variable. As a result, the hydrogeological properties such as permeability and porosity will also be variable. In depressions and on slopes siltier varieties of till may act as a confining unit capping weathered bedrock.

FELSENMEER

Felsenmeer, consisting of shattered rock fragments with minor intergranular fines, has a high porosity and permeability. Water, once it penetrates the soil zone, infiltrates rapidly into the felsenmeer. Due to the relatively thin and permeable nature of felsenmeer the water table will likely be located at depth in more competent, less shattered bedrock. Water flow will likely be controlled by the local gradient and structural elements at depth.

FURTHER RESEARCH

Several processes discussed in this paper warrant further investigation.

(1) The causes and effects of debris avalanche in the highlands should be studied on a more regional scale. It is critical for any development, such as mining or forestry, to thoroughly understand this geological process to prevent potentially dangerous and environmentally damaging avalanches. The question of prime importance is: what is the triggering mechanism of these slides, natural processes over geologic time or man-made factors? Are different types of bedrock, associated structural elements, or different types of residual or glacial materials more susceptible to avalanche? Accurate dating of avalanches may be accomplished using tree-ring chronology to aid in answering some of these questions.

(2) The effects of acid precipitation on waters draining through areas of thick, weathered bedrock require further study. The above discussion is largely theoretical in nature and should not be considered as fact. Further study of the residual materials and their acid generating and neutralizing capacity is important.

(3) The relative importance of creep, solifluction and landslide to sediment input into streams was not evaluated. This is important to the interpretation of stream geochemical anomalies since a basic catchment basin model is assumed when interpreting these data. Depending on the significance of avalanche verses creep and solifluction, this may affect such interpretations.

ACKNOWLEDGMENTS

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